Comparison of Neutron Scintillation Detectors With a ^{3}He Proportional Counter for the Spallation Neutron Source (SNS)

R. Engels, G. Kemmerling, H. Rongen, J. Schelten, and R. Cooper

***Abstract*—The performance of scintillation detectors with the advanced scintillator material ^{6}Li ^{158}Gd (^{11}BO$_3$)$_3$ was compared with conventional ^{3}He proportional counters at the IPNS spallation source at the Argonne National Laboratory, Argonne, IL. The complex neutron and gamma flux was measured with both detector types simultaneously in time-of-flight mode. Initial experiments demonstrated that both detectors have a sensitivity of about 60% for thermal neutrons. In addition, both detectors exhibited the same low gamma sensitivity.**

***Index Terms*—^{3}He counter, neutron scintillation detector, spallation neutron source (SNS).**

I. Introduction

To evaluate the performance of a prototype detector for thermal neutrons with a new scintillation material consisting of a crystalline powder of ^{6}Li ^{158}Gd (^{11}BO$_3$)$_3$ [1] mixed into a solidified polymer, neutron and gamma measurements were performed at the Argonne National Laboratory, Argonne, IL. For comparison, the data of a conventional, commercially available ^{3}He proportional from the U.S. company LND were recorded simultaneously.

The borate scintillator had a calculated absorption probability of 70% for thermal neutrons and a sensitive area of $\sim$ 5 cm diameter. The ^{3}He tube of type LND 2520 had a calculated average neutron absorption probability of 46% for thermal neutrons across its 2.5-cm diameter and a sensitive area of $\sim$ 20 cm^2 for the measurements.[1]

Time-of-flight (TOF) measurements were carried out on the QUIP instrument at IPNS with various samples in the beam and at 90° scattering angle.

The samples were:

1) an incoherently scattering vanadium rod;
2) a cadmium sheet wrapped around the vanadium rod;
3) nothing in the beam.

Depending on the sample in the beam, the detected intensity is caused by:

1) neutrons scattered from the sample;
2) air-scattered neutron in the beam line;
3) background neutrons from the target and other instruments.
4) high-energy gamma-rays generated in the target and moderator;
5) gamma-rays due to neutron absorption along the 10-m beam line;
6) gamma quanta due to neutron absorption in the cadmium target;
7) weak gamma-rays generated in Compton scattering processes;
8) cosmic rays.

Since it is not possible to distinguish between different radiation contributions, performance tests cannot be performed on an absolute basis. However, by comparing the TOF response of the new detector with that of the well-known ^{3}He detector, interpretable results can be obtained.

It is the purpose of this paper to present TOF measurements, to present various detector properties, to compare the two detector responses, and to evaluate the performance of the scintillation detector.

II. Pulse-Height Discrimination

In both neutron detectors, the gamma sensitivity is kept small by pulse-height discrimination. To adjust the discrimination levels properly, pulse-height distributions were recorded. In Figs. 1 and 2, the measured pulse-height spectra are shown and the discriminator thresholds are indicated.

In both cases, the setting is such that 80% or more of all neutron absorption events in the detector are above the threshold.

The borate scintillator spectrum indicates that the grain-size distribution of the scintillating material is very broad. Uniform grains should yield a sharp pulse-height distribution with an average pulse height, which is large if the volume fraction of non-scintillating admixture is kept small.

III. Experimental Arrangement

The TOF was measured with both detectors located off axis about 50 cm from the scattering sample. Both detectors were shielded by boron carbide plates and lead bricks. In Fig. 3, more details of the experimental arrangements are shown.

Manuscript received November 13, 2001; revised March 8, 2002. This work was supported by the SNS project via Argonne National Laboratory under Contract OF-00827.

R. Engels, G. Kemmerling, and H. Rongen are with the Zentrallabor für Elektronik, Forschungszentrum Juelich GmbH, 52425 Juelich, Germany (e-mail: r.engels@fz-juelich.de; g.kemmerling@fz-juelich.de; h.rongen@fz-juelich.de).

J. Schelten is with the Institut für Schicht- und Ionentechnik, Forschungszentrum Juelich GmbH, 52425 Juelich, Germany (e-mail: j.schelten@fz-juelich.de).

R. Cooper is with the Argonne National Laboratory, Argonne, IL 60439-4814 USA (e-mail: rgcooper@anl.gov).

Publisher Item Identifier S 0018-9499(02)06163-4.

[1]LND Inc., Oceanside, NY.

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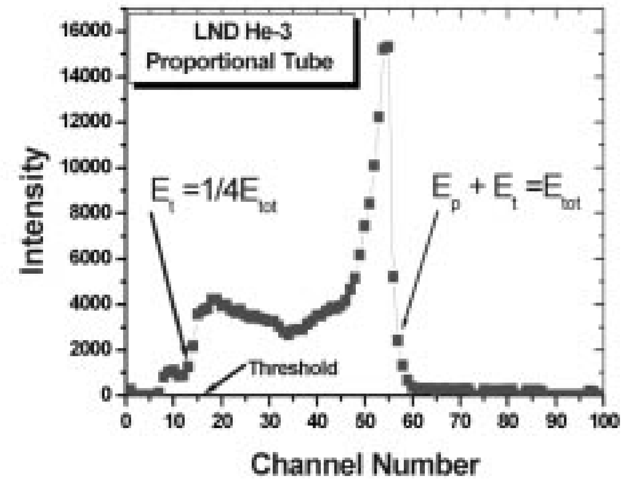

Fig. 1. Pulse-height spectrum of the LND ^{3}He proportional counter. The characteristic features are caused by different wall effects for the generated triton and proton with low and high energy and with short and long traces, respectively. The threshold is set to the lower edge of the spectrum as indicated by the blue arrow. Measurement time is 30 min.

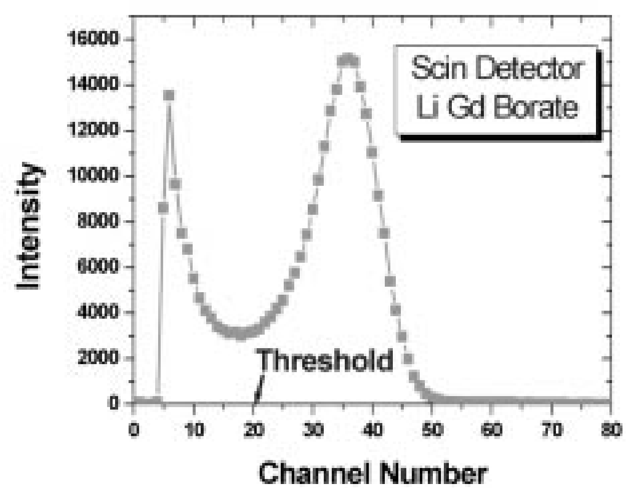

Fig. 2. Pulse-height spectrum of the scintillation detector. The broad central peak is due to wall effects of the borate grains, which are surrounded by nonscintillating plastic. Very small isolated grains give rise to small pulses. The threshold is set at the minimum of the spectrum. Measurement time is 30 min.

The analog signals from the preamplifiers attached to the detectors were fed into shaping amplifiers and discriminators. The digital discriminator outputs are connected to a D32Kitty PC card.[2] In addition, the proton on target pulse is fed into this PC card, which allows a simultaneous detection of two TOF spectra.

IV. TOF Measurements With Vanadium

In Fig. 4, the complete vanadium spectra are shown. At short wavelengths, below 1 Å, the spectrum is dominated by high-energy gammas generated in the proton target and neutron moderator. At about 2 Å, neutrons dominate because at times longer than 1 ms after T_0, the gamma intensity has drastically decayed.

[2]ProScope GmbH, Baesweiler, Germany.

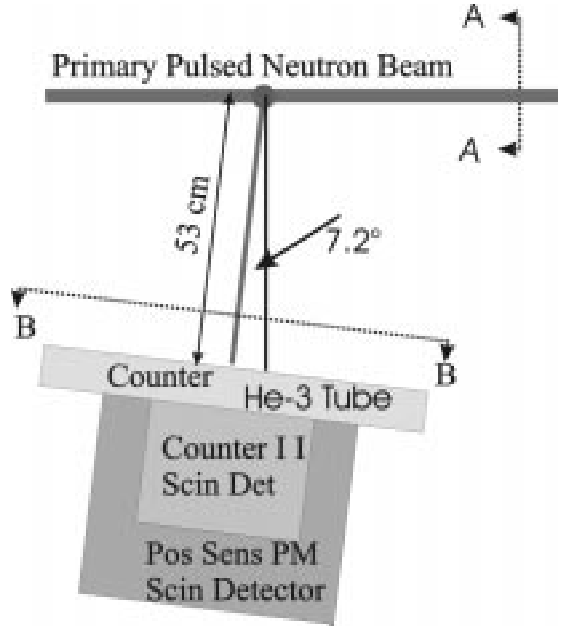

Fig. 3. Top view of the experimental arrangement. The actual scattering angle was 7.2° less than 90°.

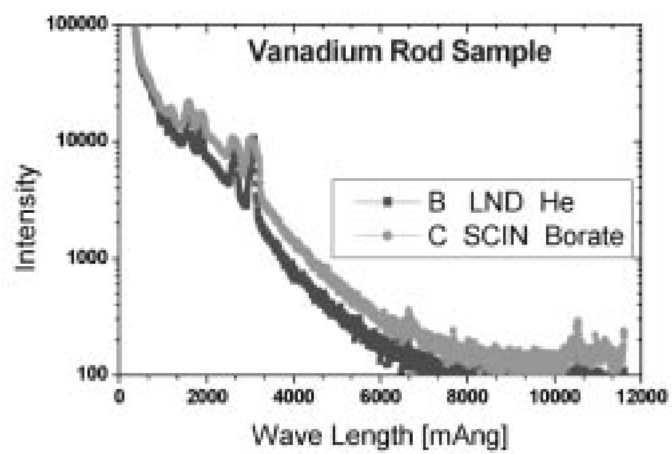

Fig. 4. Vanadium spectra as measured with both detectors in a semilogarithmic plot. Measurement time is 12 h.

Using this criterion, the ratio of the neutron count rates $I(n)$ for the two counters is 1.5

$$\frac{I_{\mathrm{Scin}}(n)}{I_{\mathrm{He}}(n)} = 1.5 \tag{1}$$

averaging over the wavelength range from 1 to 10 Å. However, the ratio is close to one when essentially gamma intensities $I(\gamma)$ are measured, which is the case for wavelengths less than $\sim$ 0.4 Å

$$\frac{I_{\mathrm{Scin}}(\gamma)}{I_{\mathrm{He}}(\gamma)} = 1. \tag{2}$$

This means that both detectors have approximately the same low gamma sensitivity. This result is meaningful for scintillation detector development, since it is the first time that a scin-

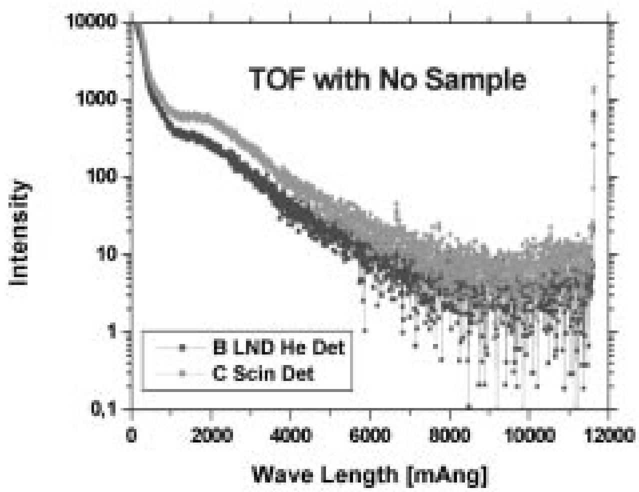

Fig. 5. TOF spectrum with no sample in the beam on a semilogarithmic plot. Measurement time is 2 h.

tillation detector can compete with a He detector for its gamma insensitivity. This result is supported by the measured TOF spectrum shown in Fig. 5 with no sample in the beam and also in another measurement with cadmium wrapped around the vanadium sample, where essentially no gammas were detected.

Historically, scintillation detectors based on the well-known commercially available ^{6}Li-glass scintillators have a gamma background that is intolerably large [2]. In this scintillator, a 1-MeV gamma pulse has the same height as a neutron pulse. However, in the new scintillator, the gamma equivalent energy is 2.5 MeV. For such a high-energy gamma, the probability of a photoelectric interaction in the scintillator is orders of magnitude smaller.

V. Conclusion

Tests of a scintillation detector equipped with the Li Gd $(BO_3)_3$ scintillator using TOF measurements with a pulsed beam from IPNS in Argonne National Laboratory has shown the following.

1) Due to the complex background at the QUIP test position, a He-3 proportional counter was necessary and only relative measurements were feasible in order to compare the results of both detectors.
2) Both detectors yielded about the same count rate in neutron and gamma fields. Thus, the gamma sensitivity of the scintillation detector with only pulse-height discrimination is as good as that of a conventional He-3 counter.
3) The gamma sensitivities of both detectors were too low to detect the high-energy gammas from a cadmium sample in the beam.
4) For a more detailed study of the remaining gamma sensitivity issues, one needs to perform experiments with the detectors in the primary beam or improve the shielding at this test station.

Acknowledgment

The authors thank I. Naday and P. DeLurgio, Argonne National Laboratory, for their kind hospitality and for many valuable suggestions and interesting discussion. They are thankful to W. Schäfer of University Bonn and H. Seyfarth of F. Jülich for providing us with diffraction data and nuclear data as well as for stimulating discussions.

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